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FALLOUT FROM NUCLEAR WEAPONS TESTS

SUMMARY-ANALYSIS OF HEARINGS MAY 5–8, 1959

JOINT COMMITTEE ON ATOMIC ENERGY CONGRESS OF THE UNITED STATES

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SUMMARY-ANALYSIS OF HEARINGS HELD MAY 5–8, 1959, ON FALLOUT FROM NUCLEAR WEAPONS TESTS

I. Introduction

The Special Subcommittee on Radiation of the Joint Committee on Atomic Energy held public hearings from May 5 to May 8, 1959, on fallout from nuclear weapons testing. It was the intent of these hearings to bring up to date the scientific information developed by the subcommittee in its 1957 hearings, including consideration of new matters; to examine alternative weapons-testing policies from the standpoint of the resulting fallout; and to learn what is being done by various Federal agencies and their contractors in the fields of research and monitoring-surveillance on worldwide fallout.

To accomplish these purposes the subject matter was restricted to problems of fallout associated with nuclear weapons tests, with the implications of all-out nuclear war being reserved for separate hearings in June.

A panel of technical advisers consisting of qualified scientists both inside and outside the Government [1] was invited to assist the committee in preparing for the hearings. With the help of the panel, a detailed technical outline for the hearings was developed and some 30 expert witnesses were invited to testify.

These witnesses were requested to present significant developments which have occurred in their particular fields of competence since the 1957 hearings. Statements for the record were also solicited from other scientists, including some who testified in the 1957 hearings but did not participate in the oral testimony in 1959.

The subcommittee utilized the technique of asking each expert witness to summarize data pertaining to a given aspect of the problem. The committee also utilized groups of witnesses in roundtable discussions, as it did in the 1957 hearings, to discuss major points and implications of new data.

A volume of material comparable in scope to that of the 1957 hearings has resulted, attesting both to the rapidly growing amount of information related to this subject and its dissemination. The committee notes, in this regard, that no other mechanism presently exists within the Federal Government for such a systematic compilation of material on fallout for the information of the public.

[1] Following were members of the panel: S. D. Cornell, Executive Officer, National Academy of Sciences; L. S. Taylor, Chief, Atomic and Radiation Physics Division, National Bureau of Standards; F. J. Weber, Chief, Division of Radiological Health, U.S. Public Health Service; John H. Harley, Assistant Director, Health and Safety Laboratory, Atomic Energy Commission; L. Machta, U.S. Weather Bureau; C. L. Dunham, Director, Division of Biology and Medicine, Atomic Energy Commission; Bentley Glass, Johns Hopkins University; Hal Hollister, Division of Biology and Medicine, Atomic Energy Commission; Paul C. Tompkins, Joint Committee on Atomic Energy consultant; W. Selove, University of Pennsylvania; William F. Neuman, University of Rochester; Dr. Russell Morgan, Johns Hopkins University (invited but could not attend).

In bringing the 1957 hearings up to date the committee considered certain key points, as listed in the committee's 1957 summary analysis. These included:

Origin of fallout;
Distribution of fallout;
Biological effects of radiation;
Tolerance limits;
Effects of past tests; and
Effects of future tests.

The committee also considered certain major unresolved questions as listed in the 1957 summary-analysis. These included:

The existence of "clean" (versus "dirty") weapons;
The degree of nonuniformity of the distribution of global fallout;
The extent of natural "discrimination" exhibited by plants and animals against hazardous isotopes such as strontium 90;
The existence of a so-called threshold for somatic (nongenetic) effects of low-level radiation;
The threshold question as regards genetic effects, and
The distinction between absolute numbers of persons affected by fallout versus percentage of the world population.

The 1959 hearings served to demonstrate that firmer support can now be found for some statements of conclusion that were at best tentative in 1957. These concern, for example, such topics as the degree of nonuniformity of worldwide fallout distribution. Similarly, the 1959 hearings demonstrated that greater assurance seems to exist over problems, considered unresolved 2 years ago, such as the so-called discrimination factor for strontium versus calcium in plant and animal metabolism.[2]

But the 1959 hearings also served to focus attention on new points of controversy such as the so-called hot-spot problem, and the importance of short-lived isotopes in fallout occurring far away from test sites. Perhaps most important, the question was raised of how to evaluate measured levels of fallout in the environment and in man in terms of some sort of measuring standard or criterion. Central to the lack of understanding on the last point were differences of opinion with regard to interpretation and application of the so-called maximum permissible dose (MPD) of radiation, from internal or external sources, and the so-called maximum permissible concentration (MPC) of radioactive materials in the body, in air, or in water.[3]

A significant achievement of the hearings was the declassification of important new information on the weapons test programs which have been conducted by the United States, Great Britain, and the U.S.S.R. Included in this information, which was made public for the first time in these hearings, was a table showing both the total

[2] "Discrimination" is a mechanism by which plants and animals exhibit a preference for certain elements thus screening out some of the radioactive material passed along to man. The concept is applied to elements, such as strontium and calcium, that are similar but not identical in metabolic behavior.

[3] Maximum permissible dose (MPD) is a recommended value of permissible radiation *dose* relating to exposure of individuals or groups to radiation under various specified conditions.

Maximum permissible concentration (MPC) is a recommended value of *quantity* of radioactive substance per unit of tissue, air or water, also relating to exposure of individuals or groups to radiation under various specified conditions.

MPD and MPC are related to one another in principle but are not always readily interchangeable. The conditions for which MPD and MPC are best defined are for occupational exposure. (For a more detailed discussion see pp. 7 and 18.)

yield and the fission yields detonated by all countries up to the present time in testing nuclear weapons. (See pp. 11, 12.) Also declassified was important new information about the content of radioactive material in the stratosphere which has become available since 1957 by means of new direct measurement techniques.

Finally, it is worth noting that the meetings of two expert groups, both held just before the hearings began, helped to reconcile differences in interpreting available data. These are the meeting of National Academy of Sciences Subcommittee on Meteorology and discussions by a special seminar group [4] assembled at the request of the Joint Committee to consider the implications of future testing. As a result of these meetings and other scientific deliberations during the 2 years since the committee's 1957 hearings, the testimony at the 1959 hearings tended to emphasize similarities rather than differences in opinion. For this reason, the hearings were more successful in bringing out points on which there is now general agreement than was true in 1957. Major unresolved questions still remain and require clearer delineation if we are to deal with them effectively. Of particular concern, in this regard, are questions involving technical implications on policy.

[4] See app. A, p. 37.

II. Summary

In summary, the major points emerging from the hearings are presented in the following paragraphs.

ORIGIN OF FALLOUT

Information developed at the hearings shows that if the test programs of all countries are considered together, the total nuclear yield resulting from these tests has increased markedly since 1954. Of the total 90–92 megatons [5] fission yield equivalent released to date, 40 megatons was produced in 1957–58. The bulk of this was detonated during 1958 in the U.S. Hardtack series and the U.S.S.R. October series. Large portions of the radioactive products produced in this latest series have gone into worldwide fallout due to detonations of large-yield weapons at high altitudes.

As in 1957, testimony at the 1959 hearings indicated that strontium 90 and cesium 137 [6] are still considered to present the greatest hazard in worldwide fallout (fallout away from the testing sites). But short-lived isotopes, such as strontium 89, iodine 131, barium 140, zirconium 95, and others, were described by several witnesses as worthy of more consideration or even potentially equal in hazard to strontium 90 and cesium 137. Similarly, long-lived carbon 14 was described as a potential long-term hazard from nuclear weapons tests.

DISTRIBUTION OF FALLOUT

The nonuniform distribution of fallout material in the stratosphere and on the ground, which was indicated in the 1957 hearings, has been confirmed. About two-thirds of the stratospheric material has been found in the Northern Hemisphere and about one-third in the Southern Hemisphere.

The estimated mean residence time [7] of material in the stratosphere is now taken as from 1 to 5 years, compared to the 5 to 10 years estimated in 1957. The shortest residence time (about a year) can be expected for debris from the 1958 U.S.S.R. tests in the Arctic.

The rate of deposition of strontium 90 showed an increase in the spring of 1959 in the northern latitudes. Testimony indicated that such an increase may be the result of seasonal fluctuations and/or southward movement of polar air masses, coinciding with the 1958 U.S.S.R. tests in the Arctic. The existence of localized hotspot areas was recognized, resulting among other things from uneven distribution of radioactive debris removed from the troposphere by local rainfall. But the relationship of these hotspot areas to worldwide fallout, if any, remains unclear.

[5] A 1-megaton bomb has the same explosive energy release as 1 million tons of TNT. The Hiroshima bomb yield was estimated at 20,000 tons of TNT, or 20 kilotons.

[6] Strontium 90 emits beta particles which have relatively low energy but which achieve a destructive effect in bone, which strontium 90 seeks in a manner similar to calcium. Cesium 137 emits both beta particles and gamma irradiation. This isotope is taken up throughout the body and presents a hazard particularly to reproductive cells.

[7] See p. 11.

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UPTAKE OF RADIOACTIVE ISOTOPES FROM FALLOUT

The content of strontium 90 and cesium 137 in food has risen since 1957, even more rapidly than the total fallout. Temporarily high levels have been found in various parts of the country suggesting that under certain conditions strontium 90 may be taken up directly without going through the soil. Therefore, a consistent degree of discrimination (i.e., the selective reduction of strontium 90 in relation to calcium) from the ground to man cannot be expected.

BIOLOGICAL EFFECTS OF RADIATION

Evidence was presented at the hearings suggesting that the magnitude of genetic effects (i.e., effects on future generations) resulting from a given dose of radiation may, contrary to the general belief in 1957, have a definite relationship to the *rate* at which the dose is delivered. The implication of this evidence is that the effectiveness of a given dose of radiation is less at low dose rates than at high dose rates, even for genetic consequences.

The biological significance of low levels of radioactivity is still largely unknown. No resolution was reached on whether or not a threshold level of radiation exposure exists below which effects such as cancer and leukemia do not result.

HOTSPOTS AND THEIR SIGNIFICANCE

The term "hotspot" is used to refer to local areas, geographically speaking, where environmental contamination levels are considered to be higher than average levels in other areas of the country with which comparisons are being made. That such hotspot areas exist was not disputed; yet one of the ambiguities in the hearings testimony was the fact that no completely satisfactory definition was presented of what a hotspot is, how the limits of such an area are defined, and what the problems involved really are.[8]

Some testimony suggested that higher radiation levels in limited areas do not, any more than other nonuniformities, increase the overall hazard of fallout to the world's population. This contention is based on the argument that the total hazard is related to the total dose of radiation received by an entire population, and is not related to geographic distribution. It is evident, however, that more data and greater consideration of how to evaluate the data are needed before a satisfactory answer to this problem can be worked out.

SIGNIFICANCE OF SHORT-LIVED ISOTOPES

According to the testimony, recent fallout samples have concentrations of short-lived isotopes which are equal to and in many cases higher than those of the longer-lived isotopes such as strontium 90 and cesium 137. Due to their relatively rapid decay, the total radiation dose they deliver is ordinarily only a small fraction of that delivered by the longer lived isotopes. However, the short-lived

[8] Prior to the hearings, the Joint Committee sent a letter to AEC, dated Apr. 7, 1959, requesting information on the hotspot problem. The outline of the hearings also specified that AEC should present detailed testimony on the problem. Following the hearings, the committee requested additional information from the AEC in letters dated May 18, 1959, and June 17, 1959. The material referred to, together with the AEC responses, is contained in the printed hearings.

isotopes may be acquiring more significance than previously thought in view of the fact that fallout from the stratosphere has proven to be faster than estimated earlier (see p. 5), together with the possibility of selective concentration in some particular organ of the body (i.e., radioactive iodine in the thyroid). The question apparently merits greater attention than it has received in the past, particularly in forecasting the effects of future tests. (See pp. 8, 29.)

SIGNIFICANCE OF CARBON 14

Information provided for the hearings suggests that radioactive carbon 14 from past weapons tests could constitute a genetic hazard to the world's population. The magnitude of this hazard has been estimated to be comparable to, and in some estimates in excess of, the genetic hazard from other fallout isotopes. One of the principal problems in making these estimates is how to assess the hazard of a dose which may be comparable in magnitude to that from cesium 137 and other genetically hazardous fallout isotopes but which occurs over a much longer time period (the equivalent of 8,000 years compared with 40 years or so). Here again, a problem was presented for which available information appears to be inadequate. Greater emphasis should be given to means by which this problem may be properly evaluated.

MAXIMUM PERMISSIBLE DOSE AND MAXIMUM PERMISSIBLE CONCENTRATION

It was generally agreed that in considering acceptable exposure limits in the context of worldwide environmental contamination from fallout, the best assumption that can be made at present concerning the relationship of biological effect to radiation dose is to assume that any dose, however small, produces some biological effect and that this effect is harmful. The testimony made it clear that much difficulty now exists in evaluating the hazards of environmental contamination from worldwide fallout. This is because of the difficulty in attempting to apply to whole populations exposed to fallout the concepts behind "maximum permissible dose" and "maximum permissible concentration," which were developed for occupational exposures to individuals under controlled conditions.[9]

Even if concepts developed for industrial application were clearly transferable, the testimony suggested confusion over such points as to how to apply existing maximum permissible concentrations for water to food in the fallout situation, how to handle diets (what time period to consider when "averaging"), and how to allow for the possible presence of other isotopes than the one being considered.

Further evidence of confusion concerning hazards evaluation in the testimony presented was given by the use, on the one hand, of industrially oriented exposure recommendations discussed above and by

[9] The standard recommended by the International Commission for Radiological Protection (ICRP) for occupational exposure of individual industrial workers corresponds to 2,000 strontium units, whereas the ICRP recommends a value corresponding to 67 strontium units as a standard for application to the general population. (Strontium units are used as a measure of body levels of strontium 90. One strontium unit is equal to one micromicro curie, i.e., one-millionth of a millionth of a curie, of strontium 90 per gram of calcium. A curie corresponds to the radioactivity of a gram of radium.) In the Summary-Analysis of the 1957 hearings it was noted that 100 strontium units was at that time the recommended standard for maximum permissible concentration of strontium 90 in man for a population, "subject to a number of serious questions and limitations."

the use, on the other hand, of comparisons with natural background radiation levels.[10] At present, it appears that each controversial situation involving fallout exposure is evaluated on an ad hoc basis, but with little understanding or agreement on how the evaluation is to be done.

EFFECTS OF PAST AND FUTURE TESTS

It was forecast that the average concentration of strontium 90 in human bone from past weapons tests will reach its maximum value in the period 1962–65. The predicted U.S. average value of 6 strontium units (S.U.) is slightly higher than for average Western populations (5 S.U.) and lower than the average for Eastern peoples (10 S.U.). Thus for testing already conducted, man's exposure to fallout radiation is and will be relatively small compared to the "normal background" radiation or the standard recommended by the International Commission on Radiological Protection (ICRP).

Assuming successive cycles of testing over the next two generations or less, following the same pattern as the past 5 years, the predicted average concentration in bone will be about 48 strontium units. This is close enough to the maximum permissible body burden of 67 strontium units recommended by the International Commission on Radiological Protection to suggest that a hazard to the world's population could result during this period.

ALTERNATIVE PATTERNS OF TESTING

Testimony at the hearings indicated that—

Underground tests can be conducted with relatively small weapons, without contaminating the atmosphere with radioactivity. Great practical difficulties exist for testing large or megaton weapons underground

Outer space tests can be conducted under conditions—among which are distance and yield of the device—which will reduce atmospheric contamination to an as yet unknown degree. To obtain test data, there exist practical problems of instrumentation which would require further tests in space to resolve.

Environmental testing is necessary to establish effects of nuclear weapons on military targets, equipment, radiation levels, etc.

GOVERNMENT PROGRAM AND ORGANIZATION

While the AEC has accelerated its efforts in fallout research in the past 2 years, particularly in sampling and analysis, the fallout program as a whole apparently has not received the high administrative level support it needs to give it the necessary impetus. Increased dollar outlays for facility and operating expenses have been useful but further improvements in the program, its administration and its organization, are required. These should include adequate staffing in the AEC Biology and Medicine Division to meet the broad requirements of an expanding program. Better coordination by the AEC of fallout information is essential. Adequate radiation standards must

[10] "Background" radiation comes mostly from naturally existing radioactive materials and from cosmic rays emitted from outer space. It is estimated that in an average 70-year lifetime a man will receive 7 to 10 roentgens from such background radiation.

be developed in cooperation with the various Federal, State, and private agencies.

The Public Health Service, which has been conducting a survey of radioactive fallout debris in milk, operates a research laboratory in Cincinnati and has a newly created staff in Washington. However, expenditures and numbers of personnel remain small.

With regard to the fallout program, increased emphasis should be placed on the "hot spot" problem, declassification and periodic publication of useful information, development and application of exposure standards, and better coordination among Government agencies in determining, controlling, and evaluating environmental hazards.

In implementing an effective program, the first job is to define clearly what the real problems are and then assign responsibilities for meeting these problems. In the process, care should be taken not to interfere with existing programs which are making major contributions to knowledge in the fallout field.

III. Important Information and Results

ORIGIN AND DISTRIBUTION OF NUCLEAR WEAPON DEBRIS

One of the major unresolved questions of the 1957 hearings was: "To what degree is the distribution of radioactive fallout uniform, or irregular, throughout the world?" The 1957 hearings indicated that data from sampling programs strongly implied a nonuniform distribution on the ground, as predicted by Dr. Machta and others but no agreement was reached as to the degree of nonuniformity that could be expected. There was some controversy as to the mean residence time [11] for which the worldwide debris could be expected to remain in the stratosphere—the range being from 5 to 10 years for different estimates.

By contrast, the present hearings indicated substantial agreement on the meaning of new information contained in the testimony or published in the scientific literature since 1957. This information included:

1. The release of data about the total yields of all nuclear weapon detonations through October 1958 (reproduced as tables I, II, and III).

TABLE 1.—*United States and United Kingdom nuclear events*

[Yield in kilotons]

Year	Total fission yield	Total fission yield from events, the total yield of which was 1 megaton or greater
1945	60	
1946	40	
1948	100	
1951	500	
1952–54	37,000	36,000
1955	200	
1956	9,000	8,000
1957–58	19,000	14,000

TABLE 2.—*Soviet nuclear events*

[Yield in kilotons]

Inclusive years	Total fission yield [1]
1945–51	60
1952–54	500
1955–56	4,000
1957–58	21,000

[1] A value of 50 percent has been arbitrarily selected for the fission to total yield ratio for all Soviet thermonuclear tests. As indicated in the tables, 50 percent is about the average fission to total yield ratio for all United States/United Kingdom thermonuclear tests.

[11] The mean residence time is the half residence time divided by 0.7. The half residence time is the time required for the amount of material in the stratosphere to be reduced by 50 percent. These concepts are analogous to the mean life and half life for radioactive decay.

TABLE 3.—*United States, United Kingdom, and Soviet nuclear events*

[Yield in kilotons]

Inclusive years	Fission yield [1]			Total yield	
	Air burst	Ground surface burst	Water surface burst	Air burst	Surface burst
1945–51	190	500	20	190	570
1952–54	1,000	15,000	22,000	1,000	89,000
1955–56	5,600	1,500	6,000	11,000	17,000
1957–58	31,000	4,400	4,600	57,000	28,000

[1] A value of 50 percent has been arbitrarily selected for the fission to total yield ratio for all Soviet thermonuclear tests. As indicated in the tables, 50 percent is about the average fission to total yield ratio for all United States/United Kingdom thermonuclear tests.

This information shows that 90 to 92 megatons fission yield equivalent have been released to date. Of this amount, less than 1 megaton was released prior to 1952, and 40 megatons were released by all countries in 1957 and 1958. The bulk of this must have been detonated during 1958 due to the fact that both the U.S. Hardtack series, and the U.S.S.R. October 1958 series occurred during this period.

2. Direct measurements in the stratosphere resulting from the high altitude sampling program conducted by the Department of Defense and the so-called Ashcan sampling program of the AEC have led to the conclusion that the stratospheric inventory of strontium 90 prior to the October 1958 weapons testing series of the U.S.S.R. was distributed preferentially in the Northern Hemisphere (about two-thirds of the total) compared with the Southern Hemisphere (about one-third of the total). A concentration peak was observed in the stratosphere over the Equator. The total amount of strontium 90 still in the stratosphere, including the input from the U.S.S.R. October 1958 series, was estimated to be about 30 megatons equivalent fission yield as of January 1, 1959.

3. Measurements of the radioactivity in rain, in soil, in air and in food have confirmed the uneven distribution of fallout strontium 90 on the ground. Testimony clearly shows that the Northern Hemisphere has received more than twice as much fallout of strontium 90 as the Southern Hemisphere, and that both hemispheres show peak values at about the 40°–50° latitudes, with much lower values at the Equator. On the basis of these measurements, the total amount on the ground was estimated as 30 megatons equivalent fission yield, as of January 1, 1959.

4. Measurements of the stratospheric inventory, including short-lived radioactive isotopes (barium 140, strontium 89) and long-lived isotopes (strontium 90, cesium 137, carbon 14)[12] together with measurements in soil, rain, and air samples, have changed the 1957 estimates of the mean residence time of fallout material in the stratosphere. The old estimate of from 5 to 10 years made in 1957 has been changed in 1959 to estimates of from 1 to 5 years, depending on where, geographically, the debris is injected. The measurements continue to show an increased rate of deposition of strontium 90 in the spring or summer and a decreased deposition rate of strontium 90 each fall or winter.

[12] See table on p. 25.

All witnesses agreed that the rate of deposition of strontium 90 could be expected to increase in the spring of 1959. However, two somewhat different explanations for these apparent annual cycles were offered. One explanation, presented by Dr. Machta, attributed this behavior to a natural meteorological phenomenon related to the circulation of the total air mass between the poles and the Equator. According to his hypothesis, sharp increases in the rate of strontium 90 deposition would be expected both in the spring of 1959 and the spring of 1960.

Another explanation, presented by Dr. Martell, attributes the effect to the fact that the U.S.S.R. tests for the past 3 years have coincided in time with a southward movement of polar air masses.[13] According to this hypothesis, a major deposition would be expected in the spring of 1959 and a minor increase the following spring.

The consensus concerning this new information appeared to be that:

(*a*) Radioactive material injected into the stratosphere close to the Equator apparently will be distributed in both the Northern and Southern Hemispheres, with about twice as much going to the Northern Hemisphere as to the Southern Hemisphere if the injections are slightly north of the Equator (11° N.).

(*b*) Radioactive material injected into the stratosphere in the higher latitudes of the Northern Hemisphere apparently will deposit almost entirely in that hemisphere, and will come down with a mean residence time in the stratosphere of 1 year or less. This conclusion is particularly significant in a broad policy sense because the tests conducted by the U.S.S.R. are in these more northerly latitudes, whereas the United States and United Kingdom high-yield tests are conducted much nearer the Equator.

5. The estimated differences in residence time do not lead to substantial differences in estimating the ultimate biological consequences of worldwide fallout of strontium 90 in large populations, because all such estimates are short in terms of years compared to the radioactive half life of strontium 90.[14] However, several significant points were brought out in the testimony:

(*a*) Estimates of the possible additional hazard due to the shorter lived materials, such as strontium 89, barium 140 and idodine 131,[15] may have to be modified. Testimony indicated that this influence may still be considered negligible compared with strontium 90 and cesium 137 over a long period of time, on the basis of present information.

However, testimony was presented strongly suggesting that short-lived isotopes cannot be ignored in estimating the hazards of worldwide fallout. On the contrary, they could constitute an important addition to the hazard from cesium 137 and strontium 90. For example, evidence was presented by E. A. Martell to show that these short-lived materials would lead to an average external gamma exposure rate at certain localities in the United States equivalent to as much as one-half of the natural background radiation rate.[16] Allowance was made by the prediction panel for this effect (see app. A), but

[13] This explanation does not account for the increased deposition rate observed in the spring of 1955.

[14] The different models differ by only 9 percent in prediction of the peak concentrations. (See app. A, fig. 2.) Strontium 90 has a half life of 28 years. Half life is the time it takes for half the radioactivity to decay. Successive half lives are used as a measure of the loss of radioactivity which ultimately approaches, but does not reach, zero.

[15] Strontium 89 has a half-life of 51 days; barium 140, 12.8 days; and iodine 131, 8 days (see table, p. 25).

[16] The natural background radiation rate is approximately 100 milliroentgens (MR) per year.

the dose rate was lowered to provide for the effect of natural shielding due to unevenness of the ground, time spent indoors, etc. (Dr. Martell's figures were computed for fission products deposited on an infinite flat plane—a theoretical, rather than an actual condition.)

(*b*) The future fallout threat from strontium 90 may have been overestimated in 1957 because the quantity of material still in the stratosphere at that time was probably somewhat overestimated.[17] leaving less to be deposited during 1958–60.

(*c*) The preferential deposition of material between hemispheres and within certain latitude bands of both hemispheres is more significant in evaluating the ultimate disposition of fission products produced by weapons testing than is the stratospheric storage (or residence) time per se.

(*d*) Local increases and decreases in the total radioactivity content of soil and food can be expected to occur in different places. This can happen, for instance, when a local rain coincides with a high radioactivity count in the air. It is reasonable to expect that "hotter" and more sharply defined "hot spots" may be created during the next 2 years due to material now in the stratosphere. (The reasons for this are explained on page 20, which contains a detailed discussion of the "hot spot" problem.) One result is continued difficulty in the interpretation and use of present surveillance measurements of worldwide fallout.

UPTAKE OF FALLOUT MATERIAL IN MILK, FOOD, AND HUMAN BONE

The testimony showed that an expanded environmental sampling program has been developed both by the AEC and the U.S. Public Health Service. The sampling networks have resulted in a comprehensive body of information regarding the concentrations of radioactive material (and amounts deposited) in air, water supplies, milk, food supplies, soil, plants, animals, and humans. Measurements have been made of many radioactive materials other than strontium 90 and cesium 137. These include strontium 89, barium 140, iodine 131, zinc 65, cerium 144, ruthenium 106, zirconium 95, niobium 95, and carbon 14. The detection of the short-lived isotopes tends to confirm the faster deposition of the fallout material, previously pointed out in the section on origin and distribution. The measurements have ranged from fallout radioactivity in well water (none could be detected) to iodine 131 in the thyroids of animals (700 to 3,000 micromicrocuries of iodine 131 per gram of thyroid tissue).[18]

Testimony indicated that almost 99 percent of the radioactive strontium 90 carried down by rain is retained by the soil and plants, resulting in much lower quantities of strontium 90 in the water supply than in the original rain.

It was also pointed out that strontium 90 and cesium 137 concentrations in milk and other foods have increased since 1957, even more rapidly than the total fallout deposition. This suggests a certain degree of direct uptake by animals and plants, which is dependent on the rate of fallout rather than on the accumulated levels.

[17] Estimates at the time of the 1957 hearings were largely based on theory whereas present estimates are based on direct measurement techniques developed in the interim period.

[18] A micromicrocurie is a millionth of a millionth of a curie and results in .037 disintegrations per second of the radioisotope.

The average concentrations of strontium 90 and cesium 137 in milk during 1958 were stated to be 7.5 micromicrocuries of strontium 90 per gram of calcium and 50 micromicrocuries of cesium 137 per gram of potassium.[19] Some samples were found ranging up to 5 times the average or 37.5 micromicrocuries of strontium 90 per gram of calcium. (Extensive tables showing the existing concentrations of radioactive materials in a wide variety of foods from different localities was submitted to the committee. This information has already been made available to the general public through the press, and will also be incorporated in the record of the committee hearings.)

In the testimony presented to the committee the general consensus appeared to be that—

1. The concentrations of radioactive materials in food and man have increased rapidly since 1957, and will probably go higher.

2. The average concentrations of strontium 90 in bone in the U.S. population were estimated to be 4 micromicrocuries of strontium 90 per gram of calcium in January 1959, and it is estimated that this figure will rise to about 6 micromicrocuries per gram of calcium in 1967 from testing already carried out.[20] Individual persons may have bone levels five times above or below these values.

3. Populations, such as those in the Orient who derive most of their dietary calcium from cereals, will have a lower discrimination against strontium 90 than those populations who get much of their dietary calcium from milk. It was estimated that the strontium 90 concentration in bone for Eastern populations would be about twice that of the Western populations in cases where the deposition of strontium 90 is the same.

4. Present evidence indicates that at some stages of plant growth, fallout material may be taken up directly by the plant without going through the soil. This mechanism was offered as a possible explanation of the high strontium 90 content of certain samples of wheat from Minnesota in 1957.

5. A consistent degree of discrimination (i.e., a selective reduction of strontium 90 in relation to calcium) from the ground to man is not expected since at least a portion of the uptake appears to depend on the rate of fallout rather than the total amount of strontium 90 on the ground. Furthermore, discrimination factors were shown to vary, at least under certain conditions, with the amount of calcium, phosphorus, and other elements in the diet. However, discrimination is still considered to be a significant factor in reducing the amounts of strontium 90 taken up by humans in relationship to the amounts in the environment.

6. Food, water, and bone show the presence of varying amounts of short-lived fission products, presumably associated with the relatively fast fallout rate.

7. Investigations of methods of intercepting these materials before they get into food or persons are underway.

8. Harvesting of contaminated row crops removed about three-quarters of a simulated fallout deposit while removal of sod and heavy mulches removed about 90 percent.

[19] The natural calcium content of milk is about 1.1 grams of calcium per kilogram of milk. The natural potassium content of milk is 1.4 grams of natural potassium per kilogram of milk.

[20] See app. A on effects of future testing.

9. Washing of vegetables removed 60 to 85 percent of the strontium 90 associated with some samples of vegetables, indicating loose material deposited on the surface of the plants.

10. The bones of children reflect their diet more closely than bones of adults do. However, the strontium-90-calcium ratios in the active part of adult bone are similar to those of children.

DEVELOPMENTS IN RADIATION BIOLOGY

1. Somatic effects

A major unresolved question from the 1957 hearings was: Is there a "safe" minimum level of radiation or "threshold" below which there is no increase in the incidence of somatic—nongenetic—conditions such as leukemia or bone cancer? Does such a level exist below which there is no decrease in life expectancy in a population resulting from radiation?

Dr. Brues, in summarizing progress during the past 2 years had this to say:

> I have to report that there is still no proof or disproof of this proposition and in fact, we cannot see where it might be coming from. This is because of the extremely small proportions of a population that would be involved at fallout levels even under the most extreme guesses. Proponents of both sides of this argument are agreed that it would take millions and more likely billions of mice—in laboratory experiments—to settle the point directly.

There were, however, several interesting points regarding somatic effects which were brought out in the oral testimony and in material presented for the record. They are:

(*a*) Laboratory experiments with animals tend to show that, for any given radiation dose, low dose rates are less effective than higher dose rates in producing tumors and leukemias. Worldwide fallout gives very low dose rates under conditions of the weapon-testing program, compared to those used in laboratory experiments.

(*b*) The work of Dr. Alice Stewart in England suggests that children who received whole body radiation, 1 to 10 roentgens, before birth while the mother was receiving abdominal X-rays, for pelvic measurement or other diagnostic reasons, have about twice the incidence of cancer or leukemia than do children whose mothers did not receive abdominal radiation during pregnancy.

(*c*) It was suggested that quantitative extrapolations from animals to man be done cautiously since each type of cancer or leukemia has its own particular sensitivity and time sequence of development.

(*d*) In a paper prepared for the hearings Dr. E. B. Lewis estimated that the thyroid glands of the average infant and young child in the United States have received doses of beta radiation from iodine 131 that is approximately equal to that which they would receive annually from natural background radiation. This estimate was based on the iodine 131 content of milk as shown by the U.S. Public Health Service and AEC measurements. The possibility that these low doses might contribute to an increased incidence of cancer was pointed out, and in his paper Dr. Lewis estimated that the numbers might possibly run from 80 to 1,600 additional cases in the United States spread over the lifetime of these individuals.

Dr. Lewis makes this significant observation about the interpretation of these estimates:

> On the linear hypothesis it is the average dose over the entire population of the United States which is important and local hot spots do not then have the alarming significance that is often attributed to them nor, from the linear hypothesis, does the individual who receives a large dose of radiation need to be alarmed, since the individual's probability of developing a malignancy remains relatively low even after heavy dose exposures.

As noted in the 1957 summary analysis, the effects of radiation on the somatic or nongenetic cells in the body apply, by definition, only to the individual receiving the radiation, not to his descendants. But whereas the effect itself appears only in the individual or individuals exposed, the incidence of the effect is spoken of in terms of a population.

The principal kinds of effects considered here are leukemia, cancer, lowered resistance to stresses, and premature aging and death attributable to no single cause. Nongenetic effects, like genetic effects, were described as being generally similar in nature to those produced by causes other than radiation. *Here again, it is the frequency of incidence that is changed. And here again, it was pointed out, no experiments aimed at observing these biological effects have ever been conducted at radiation levels very close to the natural background. As before, all conclusions based on experimental or clinical data use data obtained at higher radiation levels.*

2. Genetic effects

The testimony presented on genetic effects shows that the general conclusions of 1957 with regard to the linearity of dose and effect are still the same.[21] However, two points were stressed on the basis of work completed during the past 2 years:

(*a*) Dr. Russell's experiments on mice—involving radiation to the gonads—led to the surprising result that for a given total dose, low dose rates of radiation turned out to be only one-fourth as effective in producing mutations as the same dose given at high dose rates.[22] This result, if substantiated by further research, suggests that previous estimates of the genetic consequences of radiation may be overestimated by at least fourfold. Presumably this would also apply to estimates of somatic effects (see previous section) computed on the basis of the linear hypothesis relating dose to anticipated consequences.

(*b*) The dangers of extrapolating quantitative effects from any species to man was stressed. However, it was also emphasized that quantitative extrapolations from animal data to man are undoubtedly better than other sources, such as fruitflies.

The general consensus concerning somatic and genetic effects appeared to be that—

(*a*) For any given total dose, low dose rates are generally less effective than high dose rates in producing biological damage. (The possibility that this might be generally true was pointed out in the 1957 hearings.)

[21] According to the linear hypothesis for genetic effects induced by radiation, the biological result is proportional to the total dose and is independent of the rate at which this dose is delivered.

[22] The range of exposure to about 300,000 experimental animals was from 90 roentgens per minute to 90 roentgens per week, or a change in exposure intensity of some 10,000-fold. Total acute exposures ranged from 300 to 600 roentgens, while total chronic exposures ranged from 86 to 861 roentgens.

(*b*) This difference in effectiveness related to rediation dose rate appears to apply to both somatic (nongenetic) and genetic consequences of radiation.

(*c*) Increased evidence is developing to show that the incidence of some natural diseases such as cancer and luekemia can be related to radiation doses of less than 10 roentgens (but given at high dose rates) when unborn babies are subjected to X-rays during the pregnancy of the mother.

(*d*) More detailed evaluations will be needed to assess accurately the possible significance due to the presence of short-lived isotopes in relation to the established hazards due to long-lived materials such as strontium 90 and cesium 137.

PERMISSIBLE EXPOSURE LEVELS

The recent increase in fallout levels has led to a much sharper interest in so-called permissible exposure levels for external and internal radiation and their application to the fallout situation, particularly as regards radioactivity in food supplies. During consideration of this subject, the committee heard testimony from members of the International Commission on Radiological Protection (ICRP) and the National Committee on Radiation Protection (NCRP) who explained the history and the basis for the recommendations put forth by these groups. This was followed by a roundtable discussion.

The testimony showed that a significant area of agreement has developed on the approximate levels which could be considered appropriate. But some sharp differences exist over the way these conclusions should be reached and how the values should be applied. Most witnesses subscribe to the general point of view that radiation standards affecting the general population should not assume the existence of a threshold. Also, most witnesses appeared to subscribe to the concept that these standards should be based on a willingness to accept a level of exposure to manmade radiation, applied to a population, which bears a relationship to radiation exposure which is necessarily present from natural sources. Most authorities have estimated that lifetime exposure to such natural background radiation ranges from 7 to 10 roentgens.

Dr. Failla included in his testimony the following excerpts from the latest report of the ICRP:

> Any departure from the environmental conditions in which man has evolved may entail a risk of deleterious effects. It is therefore assumed that long-continued exposure to ionizing radiation additional to that due to natural radiation involves some risk. However, man cannot entirely dispense with the use of ionizing radiations, and therefore the problem in practice is to limit the radiation dose to that which involves a risk that is not unacceptable to the individual and to the population at large. This is called a permissible dose.
>
> The permissible dose for an individual is that dose, accumulated over a long period of time or resulting from a single exposure, which, in the light of present knowledge, carries a negligible probability of severe somatic or genetic injuries; furthermore, it is such a dose that any effects that ensue more frequently are limited to those of a minor nature that would not be considered unacceptable by the exposed individual and by competent medical authorities.
>
> Any severe somatic injuries (e.g., leukemia) that might result from exposure of individuals to the permissible dose would be limited to an exceedingly small fraction of the exposed group; effects such as shortening of lifespan, which might be expected to occur more frequently, would be very slight and would likely be

hidden by normal biological variations. The permissible doses can therefore be expected to produce effects that could be detectable only by statistical methods applied to large groups.

Dr. K. Z. Morgan had this to offer:

For the present time levels of maximum permissible exposure of the population at large to ionizing radiation must be based on estimations involving extrapolations over two to three orders of magnitude below the experimental data that can be considered to be statistically significant. For the present it is safe only to assume that types of radiation damage, such as genetic mutations, leukemic incidence, and shortening of lifespan, increase to some extent with any increase in dose taking place at any dose rate following any accumulated dose, viz, there is no threshold. However, it certainly would be ultraconservative—and at least, with respect to genetic mutation, it would be incorrect—to assume a linear relationship between dose and effect all the way from high chronic dose rates of 400 rad per 30 years to background dose rates of about 4 rad per 30 years.[23]

In discussing the values selected for the "maximum permissible concentrations" (MPC)[24] of particular isotopes in water, food, and air, Dr. Morgan noted that the MPC for cesium 137, which is deposited in the soft tissue of the body and creates genetic effects by virtue of its gamma radiation, is only about one-half as large as it could be if it were the only source of genetically effective radiation. But allowance is made for the presence of other isotopes in the fallout material that contribute to the total dose to the gonads.

This reduction is not made for materials such as strontium 90 which deposit in the bone and do not contribute to the genetic effect. Thus, the value for strontium 90 represents the concentration of that isotope in water which, if ingested for a lifetime, would not accumulate more than 2 microcuries of strontium 90 in the skeleton before death.

It was pointed out that if an allowance is to be made for the presence of short-lived isotopes with which the strontium 90 may be associated, the MPC would have to be reduced, possibly in half, to allow for the contribution of these other isotopes. This figure would then have to be divided by 30 to use the ICRP figure in practice, when applied to food and water concentrations.

New recommendations regarding exposures to radiation and radioactive materials have been developed since 1957. Certain changes should be pointed out:

1. The occupational maximum permissible amount of strontium 90 which could be deposited in the human body was raised from 1 microcurie in 1957 to 2 microcuries in 1959. This limit is based on direct measurements of the radiation toxicity of strontium 90 in animals fed on diets containing this isotope, not on the dose to the bone marrow resulting from this deposition.

2. The population maximum permissible body burden, expressed in terms of micromicrocuries of strontium 90 per gram of bone calcium, was considered to be 100 strontium units in 1957, giving a bone marrow radiation exposure rate of 280 milliroentgens per year as compared to a natural background exposure rate of 100 to 150 milliroentgens per year.[25] The corresponding values in 1959 are considered to be (*a*) 67 strontium units, giving a bone marrow exposure rate of 188 milliroentgens per year, for the general population, and (*b*) 200 stron-

[23] Dr. Morgan notes that the 30-year interval is a convenient period for considering genetic damage to man because the average fathers and mothers have begotten half their children by this age. The rad referred to is a unit of absorbed dose, used as a measure of the energy absorbed in tissue per unit mass of irradiated tissue.

[24] For a definition of "MPC", see p. 2.

[25] A milliroentgen is a thousandth of a roentgen.

tium units giving a bone marrow exposure rate of 560 milliroentgens per year, for limited sized populations in the vicinity of a controlled radiation area. (The above values are based on recent ICRP recommendations.)

3. The MPC's for other isotopes are not based on direct measurements of toxicity, but are computed on the basis of exposure to tissue. Therefore, the "standards" are not directly comparable.

Additional points that were brought out in the hearings include the following:

1. Witnesses stressed that in relating published MPC values for water and air to measured concentrations of strontium 90 in food and milk, it is the total intake averaged over some time period such as a year, not the amount in any one sample of food, that determines the significance of the measurement.

2. The ICRP and NCRP recommendations were derived for guidance and application to the nuclear industry over which close administrative control is exercised in matters of radiation protection and where individual employees voluntarily accept certain risks. Presumably, these recommendations were not designed to cope with continuing uncontrolled environmental sources such as those presented by fallout, over which the individual has no choice or control.

3. The standards do not (and cannot) set a line which is "safe" on one side, and "dangerous" on the other.

4. Application of the standards requires selective adaptations to allow for the contributions of short-lived material when they are significant, for other sources of radiation, transient exposures in excess of the standards, and other practical matters.

5. No agreement at all was reached on whether the standards should apply to population averages, to peak values for individuals as they do in occupational exposures, to individual materials, or to average diets.

It is apparent that very little, if any, progress has been made since 1957 in the development of operational information of this kind involving standards, methods of application, and criteria for decision in the management of environmental radioactivity, including that in food and water supplies. The need for development of such information was noted and documented in the summary analysis of the 1957 hearings.

"HOT SPOTS" AND WORLDWIDE FALLOUT

Testimony and material submitted for the record confirmed that worldwide fallout is not uniformly spread over the areas of the ground on which it deposits. One of the resulting phenomena is the creation of so-called "hot spots" which may encompass many square miles, such as a county, a milkshed, or a State. Such areas may be considered to exist where there are concentrations of radioactive material which lead to an external radiation dose two or three times that found in an adjacent area or strontium 90 concentrations in the soil two or three times that in adjacent areas. "Hot spots" are formed when an air mass containing a relatively high concentration of radioactive particles is associated with the deposition of rain. The water droplets forming the rain will tend to form around particulate matter in the air and carry it down to the ground.

The highest concentrations of radioactive material may be expected in the clouds from recently detonated devices. Therefore, "hot spots"

are most clearly observed in the United States during the course of operations at the Nevada test site. Because of the very young age of this tropospheric debris, such "hot spots" are relatively high both in short-lived gamma-emitting radioactive materials and in the actual concentrations present. The areas tend to be relatively small and sharply defined because the clouds have not yet had time to diffuse. An example of this condition is shown in figure 2 [26] on fallout in North Dakota in 1957 (see p. 22).

From this figure it can be seen that although a rainfall occurred over North Dakota on July 14, 1957, there was no appreciable quantity of radioactive material in the air at that time and no fallout is recorded for that date. On July 15, shot Diablo was detonated at the Nevada test site. By July 16 a portion of the cloud had traveled northeastward from Nevada over North Dakota, and as it was passing over, a relatively heavy rainfall occurred. The resulting deposition of radioactive debris was reported by Dr. Pfeiffer to be quite high (22 millicuries per square mile).[27]

The month following this deposition an increase of the strontium 90 content of milk in the area of Mandan, N. Dak., was observed. Milk levels during this period exceeded 30 micromicrocuries of strontium 90 per gram of calcium. Since that time, the strontium 90 content of milk in that area has steadily declined to a level less than 23 micromicrocuries. This observation indicates that some of the strontium 90 entering the milk supply immediately after the heavy deposit was taken in directly by cows and did not go through the soil into the forage before being ingested.

Given the mechanism by which radioactive particles are removed by rainfall from the tropospheric portion of the atmosphere, it would be predicted that where a cloud passes over a particular area during a dry period, very little of the material would be removed. Thus, the requirement that both a high concentration of radioactive particles and rain deposition must occur simultaneously is consistent with the correlation between shot dates, rainfall, and strontium 90 deposition seen in figure 2.

"Hotspots" from worldwide fallout would normally be expected to be less striking than the example shown in figure 2 because the fallout material is more evenly distributed throughout the atmosphere under these conditions. Consequently, the peak intensities for "hotspots" from worldwide fallout should be more nearly uniform and could be expected to vary by perhaps two or three times the average deposition.

The heavy injection of radioactive material into the stratosphere during 1958 resulting from the U.S. Hardtack series and the U.S.S.R. October series, coupled with the fact that this material will return to the earth with a mean residence time of 1 to 2 years, would lead to the expectation that during 1959 and 1960 the average radioactivity concentration in the tropospheric air of the Northern Hemisphere will be higher than the concentrations which were present during the period of 1954–57. There is, therefore, a high probability that more sharply fluctuating depositions of radioactive materials will occur during this period.

[26] Taken from "Some Aspects of Radioactive Fallout in North Dakota," E. W. Pfeiffer, North Dakota Quarterly, autumn, 1958, contained in the printed hearings.

[27] (See footnote above and AEC letter to the Joint Committee, dated May 13, 1959, in the printed hearings.)

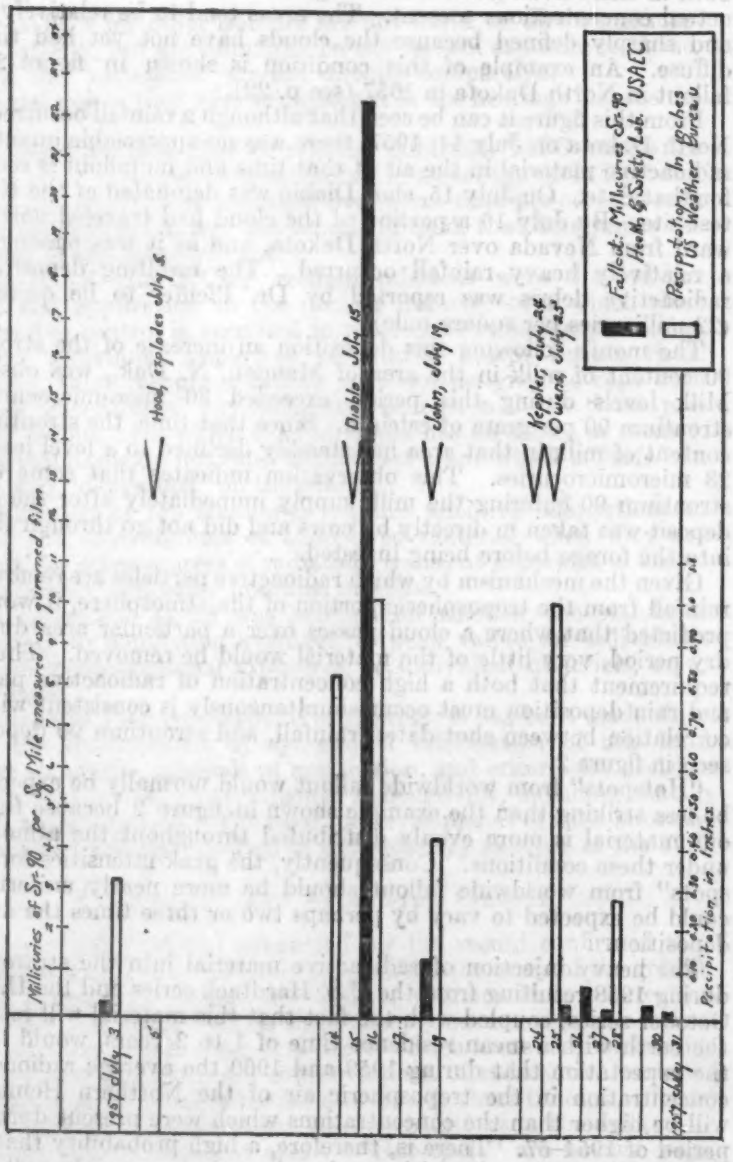
Millicuries of Sr-90 per Sq. Mile measured on gummed film
Hood explodes July 5
Diable July 15
John, July 19
Keppler July 25
Owens July 25
Fallout: Millicuries Sr 90 Health & Safety Lab. USAEC
Precipitation in inches US Weather Bureau
Precipitation, in inches
1957 daily
1957 daily

FIG. 2 — *Sr-90: Fallout and Precipitation, North Dakota*
(Prepublication Report, Health and Safety Lab., USAEC.)
(Only fallout above 0.2 millicuries/sq. mile is graphed)

Similarly, more frequent transient increases in the radioactivity content of foods, vegetables, milk, and water resulting from this freshly deposited material can be anticipated. Whether or not the actual quantities of radioactive material will reach levels comparable to that of the naturally occurring radioactive materials has yet to be determined.

No evidence was submitted to the hearings about the frequency of occurrence, size, and relative activity levels of "hot spots." Judging from the information presented, there is no reason to believe that the existence of such "hot spots" at currently known levels of radioactivity constitute an overt hazard to individuals within the areas concerned. In fact, the trend of the testimony appeared to indicate that local "hot spots "have no special significance to individuals so long as criteria are used which have meaning only in terms of a large population. Examples of such criteria are genetic consequences and somatic injuries which are reflected by a change in the incidence of a particular disease. However, the manner in which the fallout level, area, and population should be related for different conditions was not discussed, and the whole subject matter needs further examination.

For example, in using a population criterion for a radiation event, a dose of 0.1 roentgen affecting 10 million people would be considered to be equivalent to a dose of 10 roentgens affecting 1 million people. Does a similar relationship apply to fallout levels, areas affected, and the population of these areas? How high does a fallout level have to be before it is considered a hot spot? Is this level related to the number of people, the number of and level of hot spots, or some other factors?

The answers to these questions are all related to the practical application of radiation protection criteria on the basis of effects on a population instead of on individuals. From testimony presented at the hearings it is apparent that practical methods for the application of such radiation protection criteria have not yet been developed.

SHORT-LIVED ISOTOPES

The testimony made frequent reference to the presence of short-lived isotopes in worldwide fallout, reflecting the more extensive measurements which have beem made of them since 1957. The shorter residence time for fallout in the stratosphere (p. 12) suggests that short-lived isotopes should be more abundant in the fallout than would have been forecast 2 years ago.

A long-lived radioactive isotope will continue radioactive disintegration of its atomic nuclei for a long time. For instance, a given amount of strontium 90 (with a half life of about 28 years) will be disintegrating at about one-half of its initial rate 28 years later, at one-fourth of its initial rate 56 years later, and at one-eighth of its initial rate 84 years later. In 84 years, furthermore, about seven-eighths of the original number of atoms would have already decayed. In other words, about seven-eights of the possible total dose (to the surroundings absorbing the radiation) would have been delivered during the 84 years and the dose rate would be about one-eighth of the original dose rate.

For a short-lived isotope such as strontium 89 (half life, about 51 days), the radioactive material will be disintegrating at one-half

it initial rate 51 days later, at one-fourth its initial rate 102 days later, and at one-eighth its initial rate 153 days (half a year) later.

Comparing the long-lived strontium 90 isotope with the shortlived strontium 89 isotope, it is found that—

(*a*) Since the two isotopes are chemically similar, they can be expected to behave similarly in the metabolic uptake into man's body and to behave similarly in the body. (This situation does not necessarily hold for all other isotopes).

(*b*) To deliver the same total dose to the body, the initial numbers of atoms of strontium 89 and strontium 90 would have to be equal and the characteristics of the radiation from the two materials would have to be alike. The radiation characteristics are not, however, alike.

(*c*) When the initial number of atoms of strontium 89 and strontium 90 are equal, the relative initial "activity" levels would be such that the strontium 89 activity (i.e., disintegration per minute) would be many times greater because of the differing decay rates, as discussed below.

(*d*) Since strontium 89 is produced more abundantly in fission than strontium 90 and since "fractionation" may further increase the relative abundance of strontium 89 to strontium 90, it is possible that comparable doses to the body from the two materials could occur.

These relationships are illustrated in chart 1. It can be seen that the dose delivered by the long-lived materials, represented by the lower dark-shaded line, is cumulative on repetition (i.e., repeated testing). By contrast the shorter-lived materials, represented by the lightly shaded area, would have decayed away and this segment of the dose would be replenished on such repetitions.

CHART 1

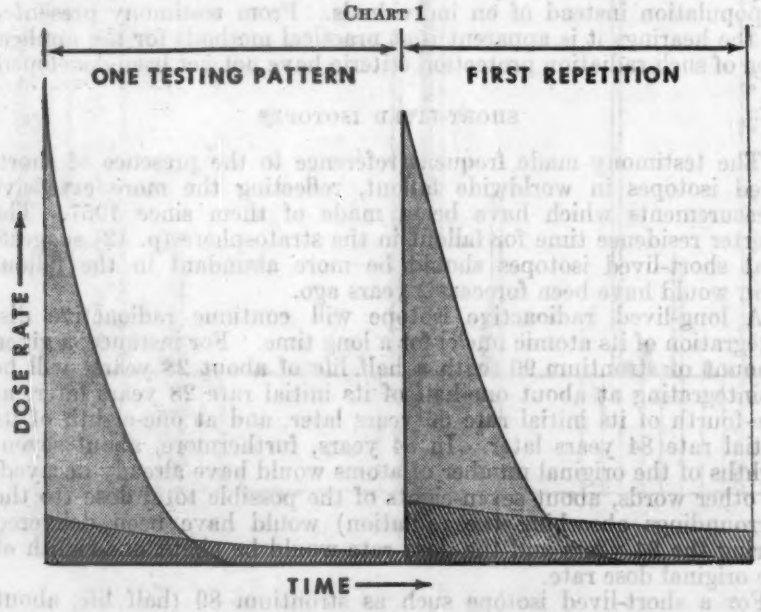

ILLUSTRATION OF DOSE RATE AND TOTAL DOSE FROM SHORT-LIVED AND LONG-LIVED ISOTOPES

Assumption: the two isotopes are chemically and biologically identical in behavior, differing only in radioactive decay lifetime.

For this reason it would require 100 times more initial activity of strontium 89, whose half life is 56 days, to deliver the same dose to tissue than would be created by 1 unit of strontium 90. It is considered significant that transient levels of strontium 89 with approximately this ratio to strontium 90 have been observed in milk. In this case, strontium 89 would follow the same path in going through the food chain that strontium 90 does.

It can be seen that, under certain conditions, cumulative doses comparable to any fixed dose rate such as the natural background rate can be developed from exposure to short-lived radioactive materials, even though the exposure due to long-lived materials may be only a few percent of natural background.

Therefore, if it is assumed that exposure to dose rates comparable to background (or comparable to any other stated level) is the basis on which the significance of radiation exposure is to be evaluated, the frequency of the appearance of the short-lived materials determines their significance, even though their relative hazards are much less than those due to the long-lived material. In this connection, U.S. Public Health Service representatives noted that it was entirely possible that in their measurements they might encounter concentrations of short-lived materials such as iodine 131 in food supplies which could be high in relation to the "maximum permissible concentration" of iodine, but which over a long period of time would constitute only a small fraction of the potential dose delivered by the fission product mixture.

Although the evaluation of the relative hazards due to short- and long-lived material was not questioned, the propriety of ignoring the short-lived isotopes in the practical application of Public Health standards was questioned. It logically follows that when the relative hazards of the radioactive materials are used as the basis on which to evaluate the significance of worldwide fallout, the conclusions have meaning only in terms of the population as a whole and over a long time period. There is no apparent correlation between this question and the question of whether or not the radioactivity content of some particular material at some particular time is, or is not, above some value such as an MPC.

The testimony presented to the committee makes it evident that the manner in which radiation protection standards should be applied in practice to environmental radioactivity affecting large segments of the population needs clarification and that further effort is needed to develop practical means for carrying out such applications.

TABLE 4.—*Half lives of important short- and long-lived radioactive isotopes in fallout*

Isotope	Half life [1]	10 half lives [2]	Isotope	Half life [1]	10 half lives [2]
Iodine 131	8.05 days	80.5 days.	Cesium 144	290 days	2,900 days.
Barium 140	12.8 days	128 days.	Strontium 90	28 years	280 years.
Strontium 89	51 days	510 days.	Cesium 137	30 years	300 years.
Zirconium 95	63.3 days	633 days.	Carbon 14	5,600 years	56,000 years.

[1] The half life is the time it takes one half the radioactivity to disappear.
[2] 10 half lives is the time it takes for 99.9 percent of the radioactivity to decay. This may be considered as the total timespan over which the radiations from the isotope are effective.

FORMATION, DISTRIBUTION, AND BIOLOGICAL SIGNIFICANCE OF CARBON 14

The implications of carbon 14 were discussed briefly in the oral testimony of the hearings, but were treated at some length in submitted papers. The information presented suggested that the long-term genetic and somatic effects of carbon 14 and fission products from testing to date [28] may be approximately equal. The fact that carbon 14 is produced in approximately equal amounts by neutrons emanating from both the so-called clean and dirty types [29] of devices, suggests that the long-range carbon 14 hazards under conditions of nuclear weapons testing may be essentially the same for either "clean" or "dirty" weapon types. The question of what practical significance the hazard has is a problem which is still subject to a number of interpretations.

Production and distribution of carbon 14

Carbon is one of the most important constituents of our environment. All living things build their bodily materials from components containing carbon as a fundamental part of their structures. Plants, through the process of photosynthesis, extract carbon dioxide from the air and convert it to complex organic materials. Carbon 14 produced by the action of cosmic rays on nitrogen in the atmosphere is an essentially constant component of this atmospheric carbon dioxide.

Carbon 14 is also produced by weapons through the action of neutrons on nitrogen in the atmosphere and appears as gaseous carbon dioxide. For an understanding of the relationship of these two sources of this isotope, it is useful to examine the actual quantities of natural and artificially produced carbon 14 in the atmosphere, in plants, in the ocean, and in other parts of the environment.

Based on information provided to the committee, the following picture emerges:

1. The total carbon 14 in the dynamic reservoir (atmosphere, ocean, and terrestial biosphere) was estimated to be about 44.3 tons before testing began.

2. As of March 1958, the total number of carbon 14 atoms produced by the testing program [30] and available to the worldwide inventory was estimated to be about 0.23 to 0.27 tons of carbon 14 distributed approximately as follows:

	Tons
Stratosphere	0.160
Troposphere	0.080
Ocean	0.020
Terrestial biosphere	0.005
Total	0.265

3. The amounts produced in the most recent U.S. and U.S.S.R. series has been estimated at about 0.29 tons in the atmosphere, raising

[28] This statement should not be taken to imply that carbon 14 and fission products have inherently equal effects for equal amounts produced, since changing the test conditions (e.g., high altitude) could change this relationship.

[29] "Clean" and "dirty" refer to the relative amounts of thermonuclear and fission yields, respectively, in the total weapon yield.

[30] Estimated at 1–5 kilograms of carbon 14 per megaton of nuclear yield and assuming that about two-thirds was returned to the ocean as insoluble calcium carbonate in local fallout. Note that this is a function of the testing conditions. Later estimates released in June by Dr. Machta in the Joint Committee hearings on biological and environmental effects of nuclear war, give the figure of 4 kilograms of carbon 14 per megaton of total yield with a range of 2 to 8 kilograms of carbon 14 per megaton of total yield.

the total inventory in the dynamic reservoir at the present time to about 0.56 tons of carbon 14. On this basis, it has been predicted that a transient increase in bomb-produced carbon 14 will be observed with the contribution per gram of carbon reaching a level equal to 50 to 75 percent of the carbon 14 produced by cosmic radiation. Thus carbon 14 activities at the level of 22–24 disintegrations per minute per gram of carbon should be observed in the atmosphere.

4. When total mixing with the dynamic reservoir has been achieved, the total carbon 14 should be increased from 44.3 tons to 44.9 tons, or an increase of about 1.25 percent in the carbon 14 content of the dynamic reservoirs. This condition will eventually be reached, if there are no more tests.

5. If additional tests are conducted at a rate which is faster than the mixing time, the carbon 14 content of air would be expected to increase in direct proportion to the total yield detonated. This would be particularly evident if moderately high altitude tests were conducted so that all of the carbon 14 is originated in the stratosphere.

6. Only about 10 percent of the carbon 14 produced by nuclear weapons tests up to March 1958 had entered the oceans at that time.

7. In order to account for the distribution of weapon-produced carbon 14 between the hemispheres, there must be a rapid enough horizontal mixing so that either the stratosphere, the troposphere (or both) are mixed with a mean time of less than 2 years.

8. Differences within one hemisphere appear to be related to local dilution with carbon dioxide, which is deficient in carbon 14 as compared to the natural equilibrium level in the atmosphere.

9. Critical factors to be determined are the residence time of gas molecules in the stratosphere, and the rate of mixing between surface and deep oceans.

10. The time interval between the incorporation of carbon in foods and the consumption of that food is less than 1 year.

11. The maximum time that the carbon 14 concentration in blood lags behind the concentration in food is about 6 months.

12. The carbon of lung tissue has a somewhat longer residence time than that of blood.

Additional questions needing investigation are:

(*a*) To what extent does carbon dioxide from decaying plants enter growing plants?

(*b*) To what extent can variation in the diet affect the lag time?

(*c*) What is the mean residence time of carbon in human soft tissue and in human bones?

Biological significance of carbon 14

Whereas most radioisotopes ingested internally cause potential biological damage as the result of ionization in tissue produced by the absorption of their radiations, carbon 14 could cause damage in two additional ways:

1. The recoil of the nucleus of the atom from the force of the ejected electron is strong enough to break the chemical bonds of the organic compound of which that particular atom was a part.

2. As the result of radioactive decay and the loss of an electron from the carbon 14 nucleus, the carbon atom becomes a nitrogen atom. Since the function of living material is dependent on the chemical configuration of the complex organic compounds, particularly in the

genes, either event could cause a deleterious mutation of cells in the body.

There was marked disagreement among the contributors to the hearing regarding the relative importance of the genetic effects produced by ionization as compared to the so-called recoil-transmutation mechanisms. For example, Dr. Pauling concluded that the dominant effect was due to the ionizing radiation whereas Totter, Zelle, and Hollister concluded that the recoil-transmutation effect was essentially equal to the ionization effect.

The genetic injury from both weapon-produced carbon 14 and fission products occurs at the moment the genetic molecule is affected as the result of absorbed radiation. The actual effect does not appear until this particular gene is found in either the sperm or ovum at the time of fertilization. This event may occur several generations after the initial injury. The subsequent discussion will consider only the relationships of dose and time concerned with the introduction of the initial injury.

Most of the injury due to fission products will be initiated within a 30-year period. By contrast, after the initial transient increase in atmospheric carbon 14 is past, half of the remaining carbon 14 injuries will be introduced over a period of 5,600 years; 75 percent in 11,200 years, and so on.

However, since the same genetic effect is ultimately expected to result from the same dose if the population is assumed to remain approximately stable, it is useful to compare the total doses ultimately expected from weapon-produced carbon 14 and fission products and compare these numbers to the natural background.

	Milli-roentgens
Total fallout genetic dose (from app. A)	50
Total weapon-produced carbon 14 (computed on the basis of 25×10^{27} atoms)	135
Natural carbon 14 dose rate (from Dr. Libby) (per year)	1.5
Total natural background dose rate (from app. A) (per year)	100

From these data, the following comparisons can be made:

1. The eventual genetic effect over more than 10,000 years resulting from weapon-produced carbon 14 is expected to be about twice that of the fission products, or about four times greater if an equal effectiveness of transmutation and recoil is assumed.

However, it should be noted that most of the initial injuries due to fission products will be caused in 30 years, whereas only half of the initial injuries from carbon 14 will be caused in 5,600 years.

This type of consideration leads to the conclusion that whereas the relative effects of carbon 14 and fission products are approximately equal, the initial injuries from carbon 14 are created over such periods of time that the continuous irradiation from natural sources will have much greater biological consequences.

2. The biological effects of carbon 14 are subject to all of the qualifications and uncertainties already discussed (p. 16), for the biological effects of low-level radiation in general. Additional uncertainty is introduced concerning the significance of the so-called recoil-transmutation effect, mentioned above. Further uncertainty surrounds the relative hazard of carbon 14 and fission products, because of the different time periods involved.

This question remains unresolved in the absence of suitable criteria for value judgments. Further consideration of this question appears to be needed.

ESTIMATING THE CONSEQUENCES OF PAST AND FUTURE TESTING

Before the hearings started, the committee requested a panel of specialists to meet and review predictions of radioactive contamination in the environment and in man. The report of this panel in its entirety is included as appendix A to this report.

The estimates were made in terms of expected levels of strontium 90 in the world's population, as well as the U.S. population, and the doses of external radiation based on the cesium 137 deposition, which could be expected to produce genetic effects. Allowance was made for the uneven deposition of fallout in latitudinal bands, but not for local variations such as "hot spots." The numerical values were derived from average levels of deposition on the ground, the resulting average external radiation dose, and the resulting average deposition of strontium 90 in the bone that would be expected from the average deposition levels.

The estimates provided for major differences in dietary habits by using a population weighted average (i.e., taking into account the number of people with a particular dietary pattern). The results predicted that the average concentration of strontium 90 in human bone would reach its maximum value in the period 1962–65, from weapons testing already carried out. Eastern peoples, subsisting largely on a cereal diet, will receive concentrations twice as high as Western peoples whose diet contains a larger proportion of dairy products as its calcium source. The predicted U.S. average value of 6 strontium units (S.U.) is higher than the predicted average for Western populations (5 S.U.) because the United States has more deposition than the average within its latitudinal band. (This is generally attributed to operations in the Nevada test site rather than to uneven global deposition of stratospheric debris.) It is lower than the predicted average (8 S.U.) for populations within the 20°–60° north latitudinal bands, despite its larger deposit, because of the large number of Eastern peoples within this land area and the effect of the Eastern diet (see p. 30).

The effects of future tests can be predicted if the future test pattern is known, or if a policy related to fallout effects exists to guide it. Since neither requirement can be met, the predictions were made on the assumption that the test pattern of the past 5 years would be repeated in successive 5-year cycles indefinitely into the future. Eventually a steady stage would be reached where stratospheric material would be falling out as fast as new material was injected; radioactive products deposited on the ground would be lost by radioactive decay as fast as new material is deposited; and the radioactivity concentrations in the different reservoirs, including bone, would go no higher.

According the panel's report, the predicted concentration in bone should be multiplied by 1.8 to determine the consequences of one repetition of the cycle, and by 8 to determine the maximum steady state level reached after 40 years. When these calculations are

carried out, the predicted future average strontium 90 bone levels in the U.S. population are as shown in table 5 below.

The radiation to the bone marrow resulting from strontium 90 deposition from tests to date was estimated to be 0.2 to 0.4 r.e.m.[31] over a 70-year period, assumed to be a normal life span for the population. This would increase the radiation exposure over that received from natural background by about 3 to 6 percent. The corresponding value resulting from continuous testing would be 1.6 to 3.2 r.e.m. in 70 years, but this rate would not be reached for 40 years. This would increase the radiation to the bone marrow by 25 to 35 percent over the natural background rates.

The U.S. average value of 48 strontium units (S.U.) resulting from repeated testing (see table 5) is close enough to the accepted maximum body burden recommended by the ICRP (67 S.U.) to suggest that a hazard to the world's population could develop at these concentrations. Since the initial value of 6 strontium units might be either too high or too low by a factor of 2, these predicted levels of 48 strontium units might develop earlier or might not be reached at all.

TABLE 5.—*Predicted average Sr^{90} equilibrium bone levels corresponding to average maximum deposition from weapons tests to date*

Region and type of population	Micromicrocurie Sr^{90}/gram Ca		
	Tests to date	After 1 repetition	After many repetitions
U.S. average	6	11	48
20° to 60° N.:			
Average	[1] 8	14–15	64
Western civilization	[2] 5	9	40
Eastern civilization	[3] 10	18	80
World average, weighted	[1] 7	12–13	56

[1] Weighted by both population and diet.
[2] Milk constitutes major sources of calcium in diet.
[3] Plants constitute major source of calcium in diet.

Source: Developed by Joint Committee at the hearings.

Similar considerations apply to estimates of the genetically effective external radiation dose which was estimated to reach a level of 0.05 roentgens or an increase of 5 percent over the naturally occurring radiation rate. Under the steady state condition which would be reached in 40 years, the external radiation would be 0.4 r.e.m., or an increase of about 10 to 13 percent over the naturally occurring rate (3 roentgens).

There are, however, certain deficiencies in this analysis which were pointed out, the implications of which should be recognized. The most important ones are:

1. In any treatment based on average values, it must be recognized that definite fractions of the population will have bone concentrations both above and below this average. The actual distribution of either the deposit or the resulting levels of strontium in bone is not known with sufficient accuracy to determine what the range might be. However, it was estimated that "significant" fractions of the population would have bone levels 3 times (18 S.U.) to 5 times (30 S.U.) the average

[31] Roentgen equivalent man: That quantity of ionizing radiation which when absorbed by man produces an effect equivalent to the absorption by men of 1 roentgen of X or gamma radiation.

(6 S.U.); a few might even have 10 times (60 S.U.) the average, based on tests to date.

2. Continued testing would, therefore, lead to a condition where a small, but unknown, number of persons could have strontium 90 bone levels as high as 500 strontium units.[32]

3. The estimated dose to the bone marrow, and the external radiation dose, do not provide for sources of radiation other than strontium 90 and cesium 137. This is not considered too significant if no more large-scale atmospheric tests are conducted. However, under a program of continued testing, the short-lived isotopes become much more important as contributors to the yearly radiation exposure levels.

4. A population weighted exposure estimate, to recognize the nonuniformity of fallout deposition, should be considered in connection with the "hotspot" problem since this problem could develop greater significance under conditions of continued testing.

WAYS OF REDUCING WORLDWIDE OR OFFSITE FALLOUT

Dr. Libby read a prepared technical statement describing alternate ways of reducing worldwide fallout. The statement is attached as appendix B.

The sense of the ensuing discussion showed that the amounts of fallout could be varied over exceedingly wide limits by varying both the yield and conditions of detonation (including location).

Four methods and their status were noted as follows:

1. Underground: Some tests have been made. Radioactivity can be almost totally confined in the melted rock. Feasibility dictates low yield devices.

2. Surface land: Good experience. About 80 percent of the debris can be deposited and made unavailable by local fallout. Adaptable to any yield.

3. Surface ocean: Good experience. About 50 percent can be pulled down by local fallout. The local fallout debris is more soluble than that from land detonations.

4. Space: Little experience. Prediction is that as much as 50 percent will come into the stratosphere at low distances (a few hundred miles) but this might be reduced to 0.1 percent at 60,000 miles.

Underground or space tests could be adapted to weapons development functions. Military effects tests can be conducted with surface or space detonations, depending on the function.

It is clear that the problem of worldwide fallout is dominated by atmospheric detonations of large yield devices. In this connection, the potentiality of conducting military effects tests with low yield devices was discussed briefly, together with the possibility of detonations underground.

[32] This can be compared to the 67 s.u. value recommended by the ICRP as a standard for application to a general population. In evaluating the significance to an individual, it should be noted that the ICRP recommended standard is 2,000 s.u., recognizing that this is intended as an occupational exposure standard.

IV. Government Program and Organization

At the conclusion of the 1957 hearings the subcommittee recommended a stepup in the AEC research program on fallout and a 5-year expansion program was formulated within the Commission. While there has been some acceleration of effort in the ensuing 2 years, particularly with regard to fallout sampling and analysis, the program as a whole has not received the high level administrative support and impetus which it needs and merits. This is true not only for the AEC but other interested agencies of the Government as well.

At the present time, about $2.5 million a year is being spent by the AEC Biology and Medicine Division on fallout sampling and analysis and about $18.5 million on research relating to the development of radiation protection standards. Much of this work is conducted in the national laboratories and in some 200 universities throughout the country. This latter amount, it should be pointed out, covers research work whose results have wide application throughout the biology and medicine program and does not pertain to fallout alone.

At the same time, other Government agencies are engaged in monitoring and research work in the fallout field. The Public Health Service, for example, has a modest environmental contamination surveillance program amounting to about $600,000 a year, including analysis of food samples from various parts of the country for radioactive content. Part of this program is financed by the AEC. The Food and Drug Administration is engaged in similar activities on a smaller scale. The Department of Defense is currently spending about $3 million a year for the high altitude sampling program and about $9 million a year for laboratory research.

For fiscal year 1960 the Atomic Energy Commission expects to increase expenditures for its sampling program to about $3.5 million and increase the research program in radiation biology to about $21 million. In addition, the Joint Committee has increased the AEC budget request for construction of facilities such as animal shelters from $2 to $3 million to assist in moving the program forward.

These increases are a step in the right direction but must be accompanied by improvements in the present program and organization, including adequate staffing of the Biology and Medicine Division to meet the requirements of an expanding program.

Aspects of the fallout program requiring particular attention are: "hot spot" areas; further declassification of information and publication in a useful form; the development and application of standards for maximum levels of exposure; and better coordination among responsible agencies of government in determining and controlling environmental radiation hazards.

In view of the mounting public concern over the "hot spot" area problem and the apparent lack of comprehensive information on these areas and their significance, the subcommittee believes it desirable that the AEC, in cooperation with the Public Health Service, institute

an accelerated investigation and surveillance program as soon as practicable to develop the necessary information for a sound evaluation of the problem.

With regard to declassification and dissemination of information, the committee believes that a more systematic approach is needed whereby pertinent information becomes available periodically to the lay public. This is particularly important to acquaint the public with matters such as strontium 90 concentration in various areas and the relationship of "hot spots" to population hazard. Availability of this information, written in understandable form, is essential to an adequate public understanding of the nature and scope of the fallout problem.

Coordinated information on fallout should be readily available on a regular basis from responsible executive agencies. The committee notes with approval, in this regard, that the Atomic Energy Commission is planning to issue quarterly summary reports on the fallout program. Such reports are to be encouraged, together with other reports in the interim periods on matters of particular interest to the public and Congress.

It is clear from the testimony at the hearings that much research work remains to be done in the development and particularly application of radiation standards governing the population as a whole. The subcommittee notes that until very recently, neither the National Committee on Radiation Protection (NCRP) nor the International Commission on Radiological Protection (ICRP) had established such standards for the population as a whole. Even in the case of the ICRP, which is the only one of the two that has made recommendations on such standards recommendations have been unclear in certain respects and are derived from standards developed primarily for occupational exposure rather than exposure of global populations.

It is evident that greater research efforts are needed by the AEC, together with the Public Health Service, in the development of meaningful standards for population exposure, not only from fallout but all other sources of radiation in the environment as well.

Along with this added research on establishment of standards, means must be found for applying these standards in practice. This is perhaps the greatest deficiency of all in the program at the present time and one which deserves concentrated attention, both by the AEC and other responsible Government agencies.

In the matter of determining and controlling environmental radiation hazards, particularly with regard to management or operational problems, there is a demonstrated need for better coordination of information and activities within the Federal Government. The subcommittee recognizes that this matter is the subject of considerable discussion at the moment, both inside and outside the Government, including a study by the Bureau of the Budget regarding responsibilities of various Federal agencies. It also recognizes that the question of assigning responsibility for research into environmental radiation hazards transcends the question of fallout alone. For these reasons, it is not the intent of the subcommittee to make recommendations at this time as to where such responsibilities should lie.

The subcommittee believes, however, that any action which is taken should be the result of a careful and objective analysis of what the real

problems are, which may well take further study and research. Once the real problems are clearly identified, then the government will be in a position to determine what specific action needs to be taken and where to fix responsibilities for such action.

In the process, care should be taken not to impede progress in existing programs which are contributing important knowledge about fallout problems. On the contrary, efforts should be made to supplement current programs with activities designed to fill existing gaps.

Finally, it should be pointed out that the results of research into fallout radiation hazards have applications into many areas of biology and medicine which are not directly connected with the fallout problem. Thus, even during a period of moratorium on further nuclear weapons testing, there is a continuing need and justification for a vigorous research program. The long-range results of this research may well have profound effects on the welfare of mankind and provide far-reaching benefits to future generations.

APPENDIXES

APPENDIX A

Statement of 1959 Fallout Prediction Panel to Joint Committee on Atomic Energy in Connection With Public Hearings on Fallout From Nuclear Weapons Tests, May 5–8, 1959

Once again at the request of the Joint Committee on Atomic Energy a panel of specialists met to review predictions of radioactive contamination in the environment and in man. Many of the scientists who were present at the 1957 hearings again participated. A list of the participants follows:

Lyle T. Alexander, USDA.
Allen V. Butterworth, AEC.
Charles L. Dunham, M.D., AEC.
Gordon M. Dunning, AEC.
Merril Eisenbud, AEC.
Edward P. Hardy, AEC.
John Harley, AEC.
J. Z. Holland, AEC.
Hal Hollister, AEC.
Harold A. Knapp, AEC.
Willard F. Libby, AEC.
Lester Machta, U.S. Weather Bureau.
Charles L. Marshall, AEC.
E. A. Martell, Air Force Cambridge Research Center.
William Neumann, University of Rochester.
J. Calvin Potts, AEC.
A. R. Shubert, Lamont Geological Observatory.
Walter Selove, University of Pennsylvania.
Robert F. Reitemeier, AEC.
Frank Shelton, AFSWP, DOD.
James Terrill, USPHS.
P. Tompkins, Naval Radiological Defense Laboratory.

The present group was charged with the responsibility of evaluating the "status and implications of testing."[1] On the assumption that the final assessment of hazard must be made in biological terms and in view of the uncertainties in the transposition of low-level radiation into expected biological effects it was possible to ignore small differences, alternate hypotheses, and alternate models. For example, for different assumed models of stratospheric distribution it was the similarities in predictions rather than the differences which seemed important.

In this frame of reference an attempt was made to summarize the total inventory of fission products produced by test explosions to date. Despite the uncertainties having to do with many of the individual tests being summated, the overall totals were of a relatively high order of certainty. These totals are given in table I.

Next, an attempt was made to estimate a rough material balance of the total fission products produced between (*a*) that deposited at or near the test sites, (*b*) that already fallen to earth as worldwide fallout, and (*c*) that still in the atmosphere. There were several methods of approaching this problem. Direct measurements of the stratosphere are now available, fission product ratios permit estimates of fractionation, and finally, direct measurements of fallout on the test sites on various occasions have been used. Despite the paucity of data and the uncertainties of each approach the agreement was remarkably good and as a summary the overall approximate distribution is given in table II.

To translate these inventories of Sr^{90} into terms which can be used to predict future bone levels of Sr^{90}, it is necessary to summate two quantities: (*a*) The dis-

[1] An outline of subject matter to be considered was furnished the group by the Joint Committee.

tribution of fallout already on the ground and (*b*) the distribution of the fission products still in the stratosphere and their probable future pattern on the ground.

The first quantity is derived from actual soil analyses for Sr^{90}. The second quantity, the distribution of fission products now in the stratosphere, is based on measurements too few and too uncertain (the Russian tests are of so recent an origin that only limited data are available) to eliminate some serious uncertainties in interpretation. The mid-1958 (the latest period for which completed measurements are available) stratospheric inventory according to latitude is given in figure 1. It was generally agreed that the bulk of the airborne inventory will fall in the Northern Hemisphere with banding in the North Temperate Zone at least as nonuniformly as has occurred for the total fallout to date. As a first approximation, it seemed reasonable to conclude that the present stratospheric inventory, when all deposited, will cause ground levels, worldwide, to double those observed in November 1958.

The estimated present (November 1958) and predicted ground levels are given in figure 2. The forecast made by Libby partitions fallout from pre-October 1958 stratospheric debris equally between hemispheres; Machta's prediction deposits twice as much in the Northern as in the Southern Hemisphere. Both estimates keep all of the October 1958 Russian debris in the Northern Hemisphere. It should be noted that fallout in the United States may be 10 to 15 mc/mi^2 higher than the predicted peak because of tropospheric fallout. The maximum cumulative levels of Sr^{90} are expected to occur in about 1962–65; Sr^{90} decay to this date has been included in the estimate.

To convert ground levels to the concentrations expected in human bone several alternate approaches were possible; i.e., extrapolation of bone levels derived from known milk concentrations, a direct conversion of ground levels by experimentally determined discrimination factors, and direct extrapolations from actual bone analyses. All these estimates of average maximum values to be expected from tests to date fell in the range of about 5 to 10 $\mu\mu c\ Sr^{90}/gc_a$ for the population in the north temperate zones. Accordingly, only one method of prediction is used here.[2] [3]

Fetal bones from the Far East run a factor of about 2 higher than those from Western populations, supposedly a reflection of difference in diet (i.e., ratio of milk to plant calcium in the diet and the higher average ratio of Sr^{90} to Ca in plants). It is necessary to weight, for population and dietary differences, the bone levels derived by multiplying deposition levels by the factor of 0.08 (which was derived on the basis of a Western diet) in order to obtain average equilibrium bone levels for other populations or for the world. Average equilibrium bone levels corresponding to estimated maximum Sr^{90} deposition as a result of weapons tests to date calculated in this way are shown in table III.

These values are averages only and make no allowances for individual variations as a result of local variations in fallout, difference in physiological status, etc. The statistical frequency distribution of the human bone values has, of course, been tabulated. However, inherent in these data are unusual problems of distribution, sampling, and analysis, all of which tend to increase the variability of the observed values. For this reason it was believed unprofitable to try to express the variability in precise statistical terms for this statement.

In addition to considering future levels of Sr^{90} contamination, the group also considered the current status of gonadal irradiation of the world population. The fallout gamma dose rate in the North Temperate Zone may be expected to double in the next few years due to the deposition of cesium 137 now stored in the stratosphere. Estimates based on current data, taking into account both short-

[2] The bone data of Kulp et al., indicate an estimated equilibrium level in bone of the Western population between 20° N. and 60° N. as of January 1958, of 2 $\mu\mu c\ Sr^{90}/g$ of calcium. This estimate is consistent with other estimates derived from Sr^{90}/Ca ratios in diet (including milk) assuming a discrimination ratio of 0.25 in going from the diet to the bone. That is to say that the average Sr^{90}/Ca ratio in bone at equilibrium will be one-fourth of that ratio in the diet. As of January 1958 the average soil deposition level in the north temperate population belt (between 20° N. and 60° N. where 80 percent of the world population lives) was 25 mc/mi^2. Dividing 2 $\mu\mu c\ Sr^{90}/g$ bone calcium by 25 mc/mi^2 gives a factor of 0.08 $\mu\mu c/g$ bone calcium per mc/mi^2. Multiplication of any estimated soil deposition level (present or future) by this factor in the north temperate population belt will give the average equilibrium Sr^{90} bone level for all populations whose diet corresponds to that of the "Western" populations.

[3] This method uses the concept of bone-soil equilibrium as a basis of computation. The equilibrium bone level is that level which should ultimately be attained if environmental contamination remained constant. With changing environmental levels, the actual bone levels lag behind the equilibrium value in time; i.e., when environmental levels are rising, bone levels will be less than the equilibrium value. The panel recognizes that environmental contamination levels will not, if there is no further testing, remain constant. Nevertheless, for the 1962–65 period this computation should give a reasonable estimate of expected levels.

lived as well as long-lived debris, are in agreement with the forecasts of the U.N. Scientific Committee on the Effects of Radiation. The worldwide external genetically significant dose, in agreement with the U.N. Scientific Committee, from short- and long-lived gamma emitters is calculated to be 10 millirad in 30 years. The North Temperate Zone gonadal dose may be taken as 2½ times the world average, or about 25 mrem. in 30 years, and to this another 25 mrem. in 30 years should be added for internal Cs^{137}.

The estimated doses to the populations in the immediate vicinity of the Nevada test site have been revised in testimony submitted to these hearings. These corrections do not significantly change the genetically significant dose to the population of the United States as a whole.

The detonations prior to 1954 were such that the stratospheric inventory in February 1954 may be assumed to have been small in relation to the debris already deposited. The doses observed by February 1954 therefore define the total to be expected from detonations up to that time. The upper limit of bone marrow dose from Sr^{90} was estimated to have been approximately 0.4 millirep. per year. This is derived from the known Sr^{90} contamination of milk in northeastern United States as of February 1954.

The panel, as a group, felt that no single or simple relation between radiation dosage and biological effect has as yet been established, particularly at the low dosages to be expected from off-site fallout. Therefore, no attempt was made to convert the predicted concentrations of Cs^{137} and Sr^{90} into the number of tumors, cases of leukemia, genetic effects, and the like. The biological effects, if any, to be expected from past tests would be manifest in a very small proportion of the world's population, but because the population is so large, the absolute numbers calculated under certain assumed relations appear startlingly large. It is useful, on an individual basis, to relate these predicted concentrations to radiation received from natural sources and to possible MPC's derived by suitably authorized committees or agencies. A comparison of fallout and natural background dose estimates appears as table IV.[4]

We find the predictions made by the 1957 panel with respect to maximum concentrations, if past tests or equivalent were repeated once, are consistent with predictions made today. It is noted that prior to 1957 approximately 50 mt. fission yield equivalent had been detonated, and since that time approximately 40 mt. more.

Submitted by:

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Joshua Z. Holland, AEC.
Hal Hollister, AEC.
Wright H. Langham, LASL.
Willard F. Libby, AEC.
Lester Machta, Weather Bureau.
William Neuman, University of Rochester.
Walter Selove, University of Pennsylvania.
Frank Shelton, AFSWP, DOD.
James Terrill, USPHS.

TABLE I.—*Total yield of test explosions to date*

[Megatons]

	Fusion	Fission	Total
All countries	80	[1] 90	170
United States plus United Kingdom		65	

[1] Of which less than 1 megaton was introduced before 1952.

[4] For doubling the past 5-year testing pattern in the next 5 years, multiply the predicted values by 1.8; for indefinitely long repetition, multiply by 8.

TABLE II.—*Estimated overall fission product distribution, November 1958*

	Megacuries strontium-90	Equivalent megatons
In atmosphere	3	30
On ground, worldwide [1]	3	30
At or near testing sites	3	30

[1] Tropospheric plus stratospheric.

TABLE III.—*Predicted average strontium 90 equilibrium bone levels corresponding to average maximum deposition from weapons tests to date*

Region and type of population	Micromicrocurie Sr^{90}/gram Ca
U.S. average	6
20° to 60° N., average [3]	8
20° to 60° N., Western civilization [1]	5
20° to 60° N., Eastern civilization [2]	10
World average, weighted [3]	7

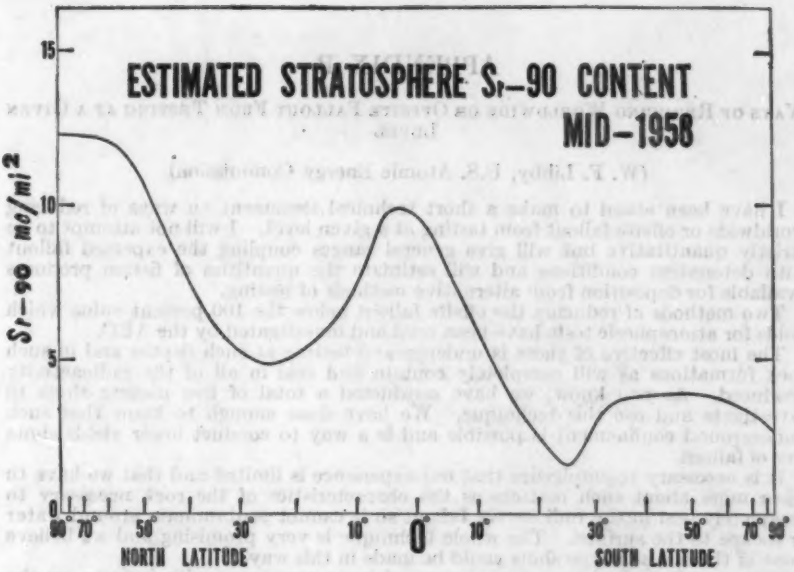
[1] Milk constitutes major source of calcium in diet.
[2] Plants constitute major source of calcium in diet.
[3] Weighted by both population and diet.

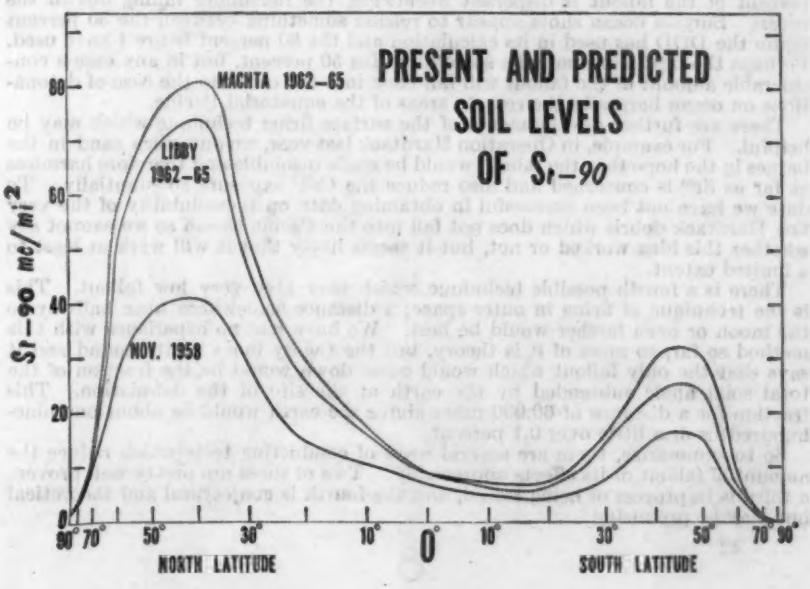
TABLE IV.—*Comparison of worldwide fallout and natural background radiation dose estimates*

[Rem]

	Predicted by this panel: dose from testing to	Natural radiation background [1]
70-year mean bone marrow dose	0.2–0.4	7
30-year genetically significant dose	.05	3

[1] Report of United Nations Scientific Committee on the Effects of Atomic Radiation, ch. III, table V.


ESTIMATED STRATOSPHERE Sr^{-90} CONTENT
MID–1958
Sr^{-90} mc/mi²
15
10
5
0
90° 70° 50° 30° 10° 0° 10° 30° 50° 70° 90°
NORTH LATITUDE
SOUTH LATITUDE


PRESENT AND PREDICTED
SOIL LEVELS
OF Sr^{-90}
Sr^{-90} mc/mi²
MACHTA 1962–65
LIBBY
1962–65
NOV. 1958
80
60
40
20
0
90° 70° 50° 30° 10° 0° 10° 30° 50° 70° 90°
NORTH LATITUDE
SOUTH LATITUDE

APPENDIX B

Ways of Reducing Worldwide or Offsite Fallout From Testing at a Given Level

(W. F. Libby, U.S. Atomic Energy Commission)

I have been asked to make a short technical statement on ways of reducing worldwide or offsite fallout from testing at a given level. I will not attempt to be strictly quantitative but will give general ranges coupling the expected fallout with detonation conditions and will estimate the quantities of fission products available for deposition from alternative methods of testing.

Two methods of reducing the offsite fallout below the 100 percent value which holds for atmospheric tests have been used and investigated by the AEC.

The most effective of these is underground testing at such depths and in such rock formations as will completely contain and seal in all of the radioactivity produced. As you know, we have conducted a total of five nuclear shots to investigate and use this technique. We have done enough to know that such underground confinement is possible and is a way to conduct lower yields shots free of fallout.

It is necessary to emphasize that our experience is limited and that we have to learn more about such matters as the characteristics of the rock necessary to completely seal in the radioactive fallout so it cannot contaminate ground water or escape to the surface. The whole technique is very promising and we believe most of the Nevada type shots could be made in this way.

The second method we know about and have experience with is firing on the surface of the land or the ocean in remote areas of the Pacific so much of the fallout will drop back into the ocean. We believe that surface land firing retains about 80 percent of the fallout on the site so if we fire on coral atolls only about 20 percent of the fallout is dispersed worldwide, the remainder falling out in the ocean. Surface ocean shots appear to release something between the 30 percent figure the DOD has used in its calculation and the 80 percent figure I have used. Perhaps the best figure may be something like 50 percent, but in any case a considerable amount of the fallout will fall back into the ocean in the case of detonations on ocean barges in the remote areas of the equatorial Pacific.

There are further developments of the surface firing technique which may be helpful. For example, in Operation Hardtack last year, we put silica sand in the barges in the hope that the fallout would be made insoluble and therefore harmless as far as Sr^{90} is concerned and also reduce the Cs^{137} exposure substantially. To date we have not been successful in obtaining data on the solubility of the very fine Hardtack debris which does not fall into the Pacific Ocean so we cannot say whether this idea worked or not, but it seems likely that it will work at least to a limited extent.

There is a fourth possible technique which may give very low fallout. This is the technique of firing in outer space; a distance somewhere near halfway to the moon or even farther would be best. We have had no experience with this method so far, so most of it is theory, but the theory looks pretty sound and it says that the only fallout which would come down would be the fraction of the total solid angle subtended by the earth at the site of the detonation. This fraction for a distance of 60,000 miles above the earth would be about one nine-hundredths or a little over 0.1 percent.

So to summarize, there are several ways of conducting tests which reduce the amount of fallout or its effects appreciably. Two of these are pretty well proven, a third is in process of being tested, and the fourth is conjectural and theoretical but may be promising.